Laser Communications Terminal for the X2000 Series of Planetary Missions

Hamid Hemmati and James R. Lesh
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

ABSTRACT

A new program called the Advanced Deep-Space Systems Development Program (a.k.a. X2000 Program) has been initiated to develop new cutting-edge technologies for NASA's deep-space missions in an overall flight project environment. Several technologies have been selected for development under the first delivery of the X2000 Program. Optical communications is one of those technologies. This paper provides an overview of the X2000 Program and describes the optical communications terminal that will be developed therein. The spacecraft terminal will be a multi-function instrument, capable of not only two-way communications from distances out to Europa (Jupiter), but two-way ranging, science imaging and laser altimeter reception as well. The plan for the development of the terminal is also described.

Key-words: Laser commonications, optical communications, telescopes, science imaging, laser altimeter reception, space missions, detector arrays, APS detectors.

1. INTRODUCTION

NASA's new space missions will require the infusion of many new technologies. It is imperative that these technologies be developed in such a way that the flight programs can easily utilize the results of the technology developments. This paper describes a new type of technology development program referred to as the X2000 Program, and the laser communications flight terminal being developed within it.

In the first section, we will provide an overview of the X2000 Program, including the identification of a "reference mission". Several technologies have been selected for development under this program, including optical communications.

In the next section we describe the architecture and performance characteristics of the flight optical communications terminal. Operational characteristics include the transmission and reception of optical communications signals, reception and turn-around transmission of optical ranging signals, and the reception of two science data types; science imaging and laser altimeter reception.

Finally, we describe the technology development program that will produce the flight-qualified engineering model terminal. This program commenced in October 1997 and is scheduled for completion in mid 2001.

2. X2000 PROGRAM

In many technology development programs, various technologies are developed by the technologists and placed on the "technology readiness" shelf for use by the subsequent user flight projects. Since these technologies are often developed from the technologist's point of view, there is danger that the ensuing technologies may not satisfy the "real" mission requirements, or at best could place additional constraints on the mission designs.

The X2000 program is a technology development program for future NASA deep-space missions. However, it is being run like a flight project with all the specific technology developers working in an integrated project environment to ensure alignment with a specific set of user missions. The program delivers flight-qualified engineering model hardware and software, with the understanding that minimal, if any, additional non-recurring engineering will be needed to deliver flight units to the user missions. The program is structured into a set of major program technology suite "deliverables". The first delivery (Delivery #1) is scheduled for completion in the year 2000, with incremental enhancements through 2001. Future technology suite "deliverables" are scheduled every two to three years thereafter.

The customer mission set for Delivery #1 consists of the Ice and Fire missions (Europa Orbiter, Pluto Express, and Solar Probe), the Champollion comet mission, and selected Mars missions. Since designing for a set of missions is complicated by the various mission constraints, the Europa Orbiter mission has been selected as a "reference mission" for design continuity. Several technologies have been selected for development as part of Delivery #1. Optical communications is one of those technologies. Due to the revolutionary nature of optical communications, it is in the set of 2001 delivered enhancements.

A drawing of the reference mission spacecraft is shown in Figure 1. The spacecraft is about 2.3 meters in height. The optical communications terminal is on the side of the "payload" module, shown on the upper-left of the lower left insert. The payload is slightly larger than a standard viewgraph projector.

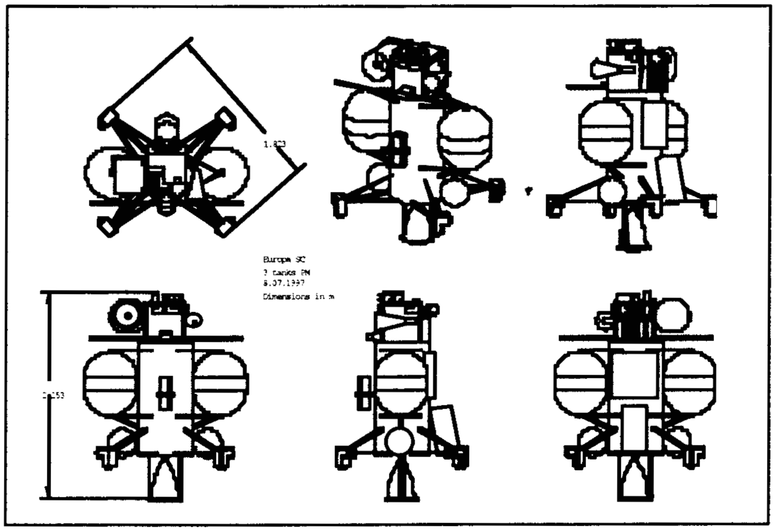

Figure 1. Diagrams of the Europa Orbiter reference spacecraft.

3. OPTICAL COMMUNICATIONS TERMINAL

The optical communications terminal being developed under the X2000 Delivery #1 project consists of three main subsystems. The first is the Optical System Assembly (OSA) which receives beacon light from the solar-illuminated Earth for use as a pointing reference and transmits an infrared (1.06 um) modulated downlink beam back toward the Earth. It also performs several other important functions, including reception of uplink command signals from Earth, reception and return transmission of Earth-generated 2-way ranging signals, collection of images of scientific interest at the target body, and reception of laser altimeter return echoes from that body. The OSA includes the Telescope Beam Assembly

(TBA), the fine-control beam optics, including the Fine-pointing Mirror Assemblies (FMA's) and the Focal Plane Arrays (FPA's), and the Uplink Detector Assembly (UDA). The FPA is used for spatial fine-beam acquisition and tracking, and for science-image capture. The UDA is a high-speed Avalanche Photodiode Detector (APD) that is used for uplink command, uplink ranging, and laser altimeter return reception.

The second portion of the system is the Laser Transmitter Assembly (LTA). The LTA contains a redundant pair of Nd:YAG laser transmitters, along with the necessary control devices to implement the downlink modulation. Diagnostic monitors of the laser transmitters are also included.

The third portion is the Electronic Processor Assembly (EPA). The EPA provides all the electronics to interface with the detectors and beam-steering elements of the OSA, formats and provides driver signals to the Laser Transmitter Assembly (LTA) for transmission of the downlink data, contains the processing to determine spatial acquisition and tracking offsets, and provides overall optical communications system control. The EPA also interfaces to the host spacecraft computer through a 1394 (Firewire) interface for high-speed transfer, and through an I^2C interface for low-rate monitor sensor data. Figure 2 shows the three subsystems of the terminal.

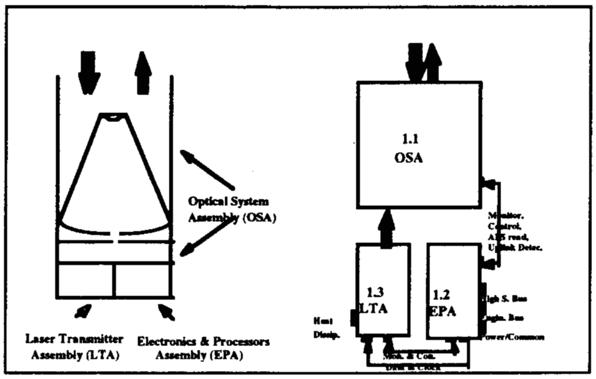

Figure 2. The three terminal assemblies

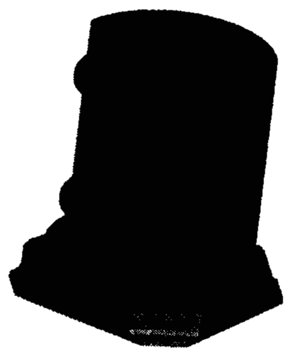

Figure 3. Layout of the terminal

Figure 3 shows the entire optical communications terminal. The telescope and the OSA's fine-pointing optics are shown via the cutout. The EPA and the LTA are located under the base for the optics.

The downlink data rate capability for the terminal is shown in Figure 4 for transmission back from Europa. Clearly the terminal can support well over 100 kbps during the daytime and almost 400 kbps during the nighttime. The planned operational data rates for the reference mission are 80, 160, 240 and 320 kbps. These rates are much higher than the typical 10 kbps or so possible with reasonable-sized RF systems, and they are enabled by using Pulse Position Modulation (PPM) with matching Reed-Solomon (R-S) coding for error control. A 2 kbps uplink capability is planned for occasional command uploads. It likewise will use PPM modulation and R-S coding. Much higher data rates (as much as several Mbps) are possible from a similar terminal if used at shorter ranges (e.g. Mars).

Figure 5 shows a block diagram of the system. The architecture of the terminal is based on the design of the Optical communications Demonstrator (OCD), an earlier-developed laboratory engineering model terminal [Ref. 1-6]. Light from the beacon signal, or the target science image if used in the science imaging mode, is received by the telescope (shown by the clear arrow), passed by beamsplitters 1 and 2 (BS1 and BS2), and is detected by the Focal Plane Array (FPA). If receiving the beacon, the position of the beacon signal on the FPA determines the orientation of the telescope. Uplink command or ranging signals are received by the telescope, passed by BS1 but deflected by BS2 to the slow-speed Beam Mirror Assembly (BMA) and then to the Uplink Detector Assembly (UDA). Transmitted optical energy from the Laser Transmitter Assembly (LTA) is sent to a high-speed BMA for fine-beam steering, is deflected off BS1, and passes out the telescope in the desired direction. A small portion of the transmit signal passes through beamsplitter BS1, and, after retro-reflection back to it, is deflected through BS2 and detected by the FPA.

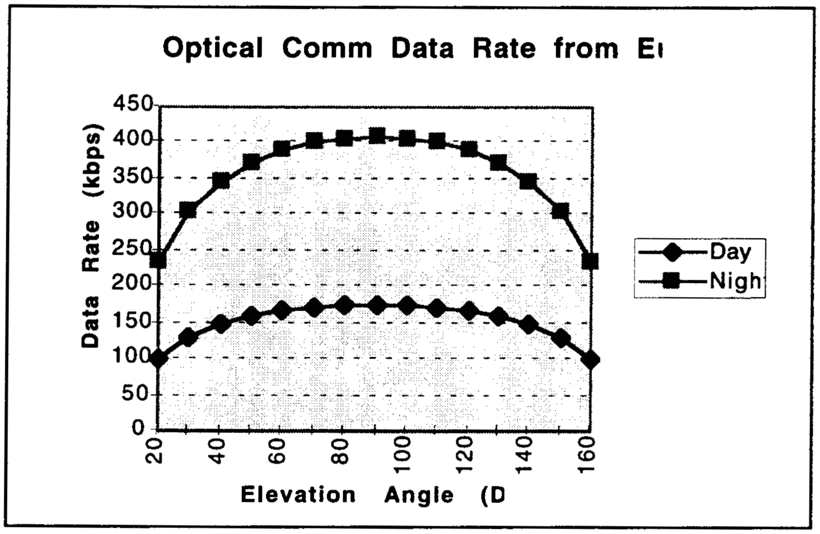

Figure 4. Data rate capability from Europa

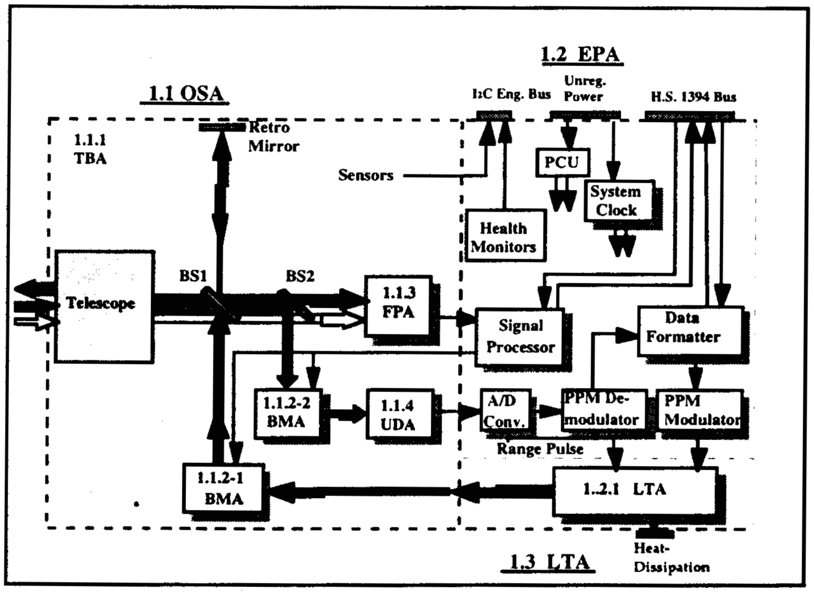

Figure 5. Block diagram of the optical communications terminal.

Images detected by the FPA are read into the EPA where a signal processor handles the data. If received in the science imaging mode, the data is formatter and sent to the spacecraft data storage system via the high-speed 1394 bus. If in the communications mode, the beacon signal is processed to determine the transmit pointing corrections (based on the location of the beacon, a sampling of the transmitted beam, and any point-ahead information received from the spacecraft control computer) and adjusts the BMA as appropriate. The EPA's signal processor may also periodically send beacon images to the spacecraft processor for calibration purposes.

Data received by the UDA is A/D converted and the resulting signal is applied to the uplink PPM demodulator. However, if the uplink signal is a ranging pulse (i.e. when the system has been placed in the ranging mode), the detected pulse is sent directly to the LTA to trigger a downlink pulse. Demodulated uplink data is sent to a formatter, whereupon it is relayed via the 1394 bus to the spacecraft control computer. Data to be sent to the ground is received by the data formatter in the EPA via the 1394 bus, and is sent to the PPM modulator. The modulated signal is then applied to the LTA.

The EPA also supports some necessary housekeeping functions These include high-speed clock signal generation, residual power conditioning and health and status monitoring.

4. TERMINAL DEVELOPMENT PLAN

The development of the X2000 optical communications terminal was initiated in October of 1997, with scheduled delivery to the X2000 project in April of 2001.

In the first year, four risk-reduction developments will take place. The first is the development of an End-End Communications Breadboard. This will functionally demonstrate the signal modulation, demodulation, and temporal synchronization functions for both the uplink and the downlink, as well as the turn-around ranging function. Interface with the breadboard will be via the 1394 interface, where CCSDS-formatted data will be passed to the breadboard for handling. The second is a breadboard to demonstrate the Earth-image tracking function. This breadboard will include the FPA, BMA and breadboard control electronics, as well as Earth-image and straylight simulators. The other two risk-reduction activities involve the evaluation of candidate LTA's and BMA's. Along with these risk reduction tasks, the initial design of the overall system will commence. Figures 6 and 7 show the structures of the two risk-reduction breadboards.

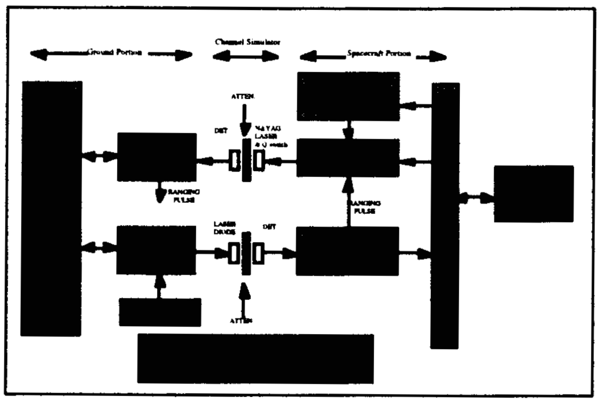

Figure 6. End-end Comm Breadboard

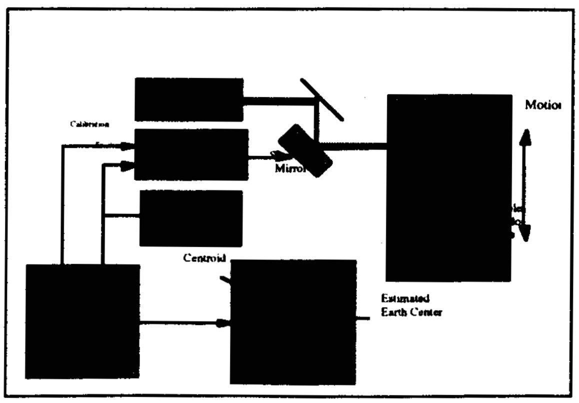

Figure 7. Earth-image ACK/TRK BB

In the second year, the detailed design of the terminal will commence. This will make use of the results of the risk-reduction activities performed in the first year, and will extend those designs to flight-qualifyable packaging. Fabrication, integration and alignment will take place in the third year, followed by functional and flight-environmental testing. A test station previously developed by JPL [Ref. 7-8] will be modified to support the program. In April of 2001, the system will be delivered to the X2000 project for testing in a simulated flight-environment.

5. CONCLUSIONS

The X2000 Program is a new paradigm for the development of space technologies. Optical communications has been selected for development in the program's first-delivery suite. The terminal being developed will be capable of providing two-way communications, two-way ranging, science imaging and laser altimeter reception. Data rates in the 100-400 kbps range are possible from Europa distances. These rates increase to several Mbps if a similar terminal were to be used from Mars. The architecture of the terminal was described, as was the development plan for its realization. A flight-qualified engineering model of the terminal is scheduled for completion by 2001.

ACKNOWLEDGMENTS

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